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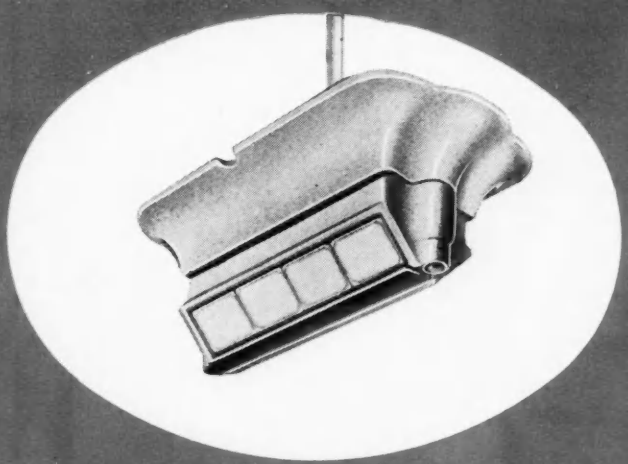

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FEATURES

DESIGN OF AIR BLAST TUNNEL BURNERS.—By W. E. Francis

DISH WASHING IN THE INDUSTRIAL CANTEEN.—By Gastronome

ROASTING COCOA NIBS BY GAS

IMMERSION TUBE HEATING OF AQUEOUS LIQUIDS.—By E. A. K. Patrick and E. Thornton

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Editorial

Increased Heating Efficiency

WE are publishing, this week, two papers read at the Autumn Research Meeting of the Institution of Gas Engineers last November. Both these papers are of considerable interest to industrial gas users and to the manufacturers of industrial gas equipment, as the discussions that followed them confirm. Such papers help to make clear the advantages to be gained from the use of gaseous fuels on a large scale.

The first paper, 'Immersion Tube Heating of Aqueous Liquids,' by Mr. E. A. K. Patrick and Mr. E. Thornton, both of the London Research Station of the Gas Council, is perhaps unduly academic since it deals exclusively with experimental work on existing industrial installations employing gas-fired immersion tube heaters. From the results obtained the authors were able to formulate an equation connecting heat efficiency of such an installation with the length and diameter of the tubes.

The other paper, 'The Design of Air Blast Tunnel Burners,' is by Mr. W. E. Francis, of the Midlands Research Station of the Gas Council, and is a further instalment of a previous paper on this subject by him in collaboration with Dr. B. Jackson. The first paper described the design of tunnel burners while this explains their more practical aspects. In fact, Mr. Francis goes into so much practical detail and discusses the advantages to be gained from each design in such a way that burners could be constructed from the information given.

A means of calculating the efficiency of this type of burner is the measurement of its pressure efficiency. This particular quality confers such benefits as high gas input to a burner of given size or a high exit velocity for a given air pressure. In this way designs may be compared, but on this basis the older existing designs were of low pressure efficiency. In the modern designs described in the paper, many drawbacks have been overcome and all these burners are of high pressure efficiency. There does not seem to be any reason, therefore, why gas-fired industrial plant using this type of burner should not now be fully exploited. In the past there seems to have been some controversy as to whether furnaces should be fitted with tunnel burners at all, but since this continues to be done it would appear that any doubt is actually groundless and there must be some real economic advantages to be gained from their use. To investigate this a large number of comparative tests would be necessary under similar loading conditions. Such a series of tests would involve fundamental furnace design, since each furnace should be designed to make the best use of its burner system.

Such papers as these are of value both to the industrial gas engineer and to the industrial gas user. The former, we think, should be kept up to date with the potentialities of modern industrial gas-burning techniques, and thus be better equipped for his task of improving gas furnace design; while the latter, always on the lookout for less costly and more efficient means of heating, and means of avoiding damage to his products during heat processing or an unnecessary number of rejects in mass production work, will know that such investigations are being made to help him attain these ends.

ABSTRACT AND DISCUSSION OF A PAPER TO THE I.G.E. AUTUMN RESEARCH MEETING

Design of air blast tunnel burners

By W. E. FRANCIS, B.A.,

Midlands Research Station, Gas Council

THE information given in this paper enables practical tunnel burner systems of improved pressure efficiency to be constructed for use in industrial gas appliances.

Effectiveness differs

In an air blast tunnel burner, air under pressure is used to inject gas from a supply at, or near, atmospheric pressure. The air-gas mixture is burned completely in a refractory combustion chamber; the resulting combustion products issuing from the burner exit at a temperature close to that of the flame can have considerable velocity. Different designs of tunnel burners do not produce appreciable variations in exit gas temperature or heat release for a given gas input. However, they may differ greatly in the effectiveness with which air supply pressure is utilised. From this point of view, the overall effect of the processes occurring in the burner is the conversion of air supply pressure to velocity pressure of exit combustion products. The efficiency of this conversion has been defined as the pressure efficiency of the burner, and a high-pressure efficiency confers such practical benefits as high gas input to a given size burner or high exit velocity for a given air pressure.

In a previous paper,* tunnel burners were compared on a basis of pressure efficiency and it was found that the pressure efficiencies of existing types were very low.

Sufficient details of burner dimensions were given in this paper to enable improved burners to be constructed, but it was obvious that more work was necessary on other aspects of tunnel burner design before the improved burners could be fully exploited in practice.

Such aspects included combustion chamber length, stability limits, design of burners with shaped exits, operation with preheated air, reduction of noise, length of burner life, and heat transfer from the combustion products.

In an air blast tunnel burner, the injector may consist of an air nozzle together with either a simple parallel mixture tube or a combination of throat and diffuser usually known as a venturi injector. The combustion chamber can be a simple cylindrical tunnel or may be terminated by a converging exit nozzle. A variety of burner types may be constructed from the possible combinations of injector and tunnel by alteration of the relative sizes of the basic components.

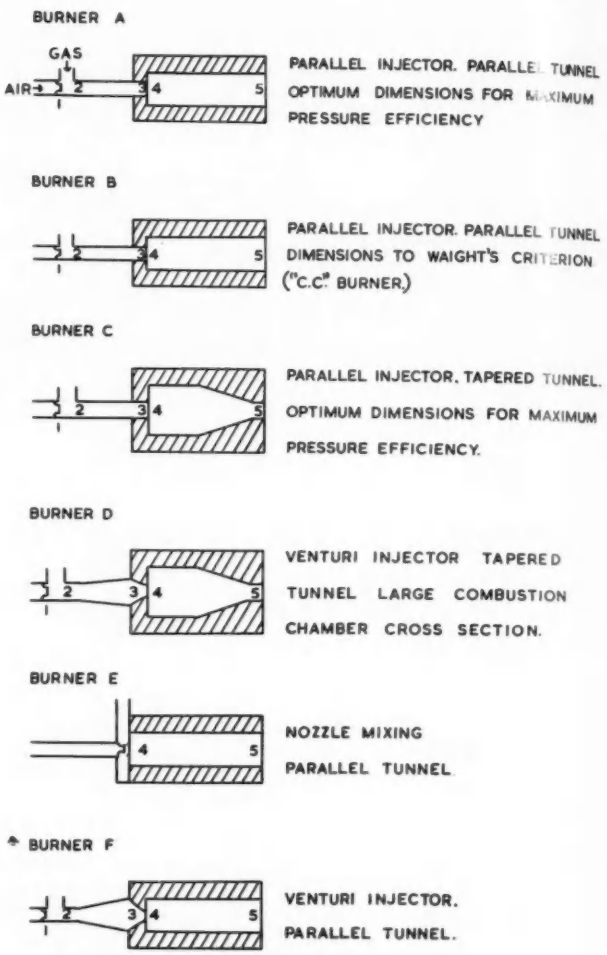


Fig. 1. Types of air blast tunnel burner.

Pressure efficiency

Fig. 1 illustrates common types of air blast tunnel burner.

The burners differ chiefly in the

* 'Jet Burner Design for Pressure Efficiency, Using Air Blast Injection.' Francis, W. E., and Jackson, B. *Gas Council Res. Comm. GC44.*

efficiency with which air supply pressure is converted to velocity pressure of exit combustion products, i.e., in their pressure efficiencies. The burners are, therefore, compared on the basis of pressure efficiency, as in Table 1. The pressure efficiency depends on the relative cross-sections of the burner components, which are given in Table 2.

Two cases are of particular interest. Burner E is an extreme case of the parallel injector, parallel tunnel combination in which no mixture tube is present and injection and combustion take place simultaneously, giving the so-called nozzle mixing burner. Burner E has high stability, since it operates in a permanently lit-back condition.

Some air blast burners are made with diverging refractory tunnels or with very short tunnels. Combustion is not necessarily completed inside the tunnel, so the systems defy analysis by the methods of *Research Communication GC44*. However, the burners can be designed by assuming all the mixture static pressure from a venturi injector is dropped across the mixing nozzle, i.e., that there is approximately atmospheric pressure in the tunnel. Burner F1 corresponds closely to this system, as far as pressures are concerned, since velocities and, hence, static pressures are approximately equalised in mixture nozzle and tunnel. It is, therefore, suggested that the air-nozzle and mixture-tube dimensions of burner F1 can be used for burners that throw negligible back pressure due to the tunnel.

All information

The choice of burner type for a given duty, and the relation between burner size, gas throughput and air pressure was discussed in detail in the previous paper (GC44). The present paper contains all the information, in Figures and Tables, necessary for constructing an air-blast tunnel burner, once the burner type and size has been decided.

Salient considerations are the relations between the burner size (represented by air-nozzle diameter), gas throughput, and air pressure. In general, two of these are known and the third is found from the Figures.

It has been shown that the more efficient air blast burners are sufficiently stable for normal industrial use. They are capable of operation under automatic control and with automatic ignition and flame-failure protection, may be used with preheated air, and may be constructed in special shapes.

There seems little reason why the advantages of the new burners should not now be exploited, since the present work has shown that there are no great practical disadvantages.

There are many tunnel burners, in use in industrial appliances, that fall short of the standards of pressure efficiency that have been attained in the burners described in *Research Communication GC44* and in the present paper. There may be advantages to be gained from the higher velocities or larger gas throughputs that would be obtained by replacement of tunnel burners in the present designs of appliances by the newer burner types. This may be difficult in the case of appliances already in use, except in special circumstances where a reconstruction or major repair is undertaken, but new productions of existing designs could incorporate the new burners.

As far as new designs are concerned, the improved air blast tunnel burners provide the appliance designer with a compact heat source and a powerful stream of hot combustion products that may be made to do considerable mechanical work to aid heat transfer, gas flow and gas mixing. The possible applications are by no means fully exploited, although progress has been made in applications such as local heating, indirect-fired air heaters, radiant tubes, and high-speed drying. The burners provide also an opportunity for use of novel or unconventional heating methods in industrial gas practice.

TABLE 1.

Pressure Efficiencies of Burners shown in Figure 1.

Calorific Value (B.t.u. per cu. ft.)	Burner Type								
	A	B and E	C	D1	D2	D3	F1	F2	F3
1	2	3	4	5	6	7	8	9	10
450	0·189	0·072	0·287	0·30	0·28	0·21	0·030	0·114	0·150
475	0·192	0·073	0·293						
500	0·195	0·074	0·297						

Definite advantages

There is some controversy over the possible advantages to be gained by using tunnel burners in furnaces. However, the fact remains that a great number of tunnel burners are used in furnaces covering a range of temperatures and types of load. It must be presumed that the furnace designers found definite economic advantages in the use of such burners, although it is difficult to find out in any particular case just what these advantages were. It seems necessary to conduct comparative tests, on a reasonable scale, of furnaces under the same loading conditions, but fired with different burner systems. Since a fair comparison is possible only if each furnace is designed to make the best use of a particular burner system, a test of this nature would involve the fundamental basis of furnace design.

More work is still required on several aspects of tunnel burner design, principally on the reduction of burner noise, on life testing and on heat transfer rates and heating times in local-heating applications.

Some information on reduction of burner noise has been given, and investigations on this aspect are being continued.

Noise production by tunnel burners may be greatly affected by tunnel length. Although noise should not

TABLE 2.

Burner Cross-sections.

Area ratio	Calorific Value (B.t.u. per cu.ft)	Burner Type									
		A	B	C	D1	D2	D3	E	F1	F2	F3
1	2	3	4	5	6	7	8	9	10	11	12
$A_1 : A_5$	450	0·134	0·0825	0·165	0·169	0·162	0·141	0·0825	0·0689	0·104	0·119
	475	0·136	0·0836	0·168	0·170	0·163	0·142	0·0836	0·07	0·1043	0·120
	500	0·138	0·0844	0·170	0·171	0·164	0·143	0·0844	0·0705	0·105	0·121
$A_3 : A_5$	450 to 500	0·372	0·135	0·51	1·0	0·75	0·5	—	0·141	0·25	0·36
$A_4 : A_5$	450 to 500	—	—	3·75	7·4	5·55	3·7	—	—	—	—

Subscripts—$_1$ Air nozzle. $_3$ Mixture nozzle or mixture tube exit. $_4$ Combustion chamber. $_5$ Exit nozzle.

normally be a serious consideration when the burner is confined in a closed appliance, such as an oven, a furnace or a radiant tube, it might become important when a burner is used in the open, as in local heating applications. For these, it is important to achieve high heat transfer rates and, hence, high exit velocities. A burner with a high-pressure efficiency should therefore be used and type C is an obvious choice both from the point of view of pressure efficiency and also because type-C burners apparently show no tendency to emit excessive noise due to oscillatory combustion.

Experiments have also yielded information on the heat transfer rates to be expected from high-velocity tunnel burners. It was found that the effective overall heat transfer coefficient, calculated from measured heating rates from the burners, was very close to the convective heat transfer coefficient calculated from the usual formulæ. Theoretical flame temperatures were used for the calculations. It seems that, for design purposes, a first approximation to heating times may be obtained by using standard convection equations and ignoring radiation from the burner.

Future developments in tunnel burners are likely to lead to the use of higher velocities and, hence, much higher air pressures; at these, the assumption of incompressible flow (on which the designs of burners described in this paper were based) will no longer be valid and it will be necessary to investigate the design of tunnel burners for use under these conditions.

For the air pressures in common use at the present time, the information given in this paper should enable practical air blast tunnel burner systems, of high-pressure efficiency, to be constructed and applied to a variety of industrial gas heating processes.

DISCUSSION

Mr. A. C. Jennings, Industrial Gas Officer, West Midlands Gas Board, said: Last year Mr. Francis, with his colleague Dr. Jackson, gave us a theoretical treatment of the subject of air blast burner design. He has now amplified and clarified the work which he and his team at Solihull have been doing in this very important field.

The comment on [Table III, p. 12] is a measure of the great increase in pressure efficiency which has been made available by the correct sizing of the various sections of the burner. We are of course taking it for granted that the pressure efficiency is a true measure of its overall efficiency. That it is a measure of operating efficiency I have no doubt, but overall efficiency includes such things as ability to operate for long periods and ease of maintenance and repairs, etc.

Why have existing air blast burners, having diverging tunnels, been used so extensively in the past in preference to burners having a high nozzle velocity? I suggest the reasons are that the manufacture of a diverging tunnel is simple and could take place *in situ*. Tunnels may be manufactured from ramming material, their ignition is easy, and they are able to operate over a very wide range of air : gas ratio. The high velocity type of burner with either a straight or converging tunnel is difficult to manufacture, the technique of the design of the equipment, using such burners, would be unconventional and until Mr. Francis's work with ignition plugs was done, ability to ignite the burner within the tunnel was difficult.

Do we need high velocity products from our burners? I would say that we undoubtedly do. If we have our products available at high velocity our equipment could be so designed as to utilise the convection component of heat transfer to a very much greater degree than has been possible in the past.

In connection with the design of production burners using the data provided in this paper, the one section of the burner which seems to provide a possibility of further improvement is the mixing tube between the air injector and the tunnel. Mr. Francis has indicated that the length of this tube should be of the order of seven diameters for a straight tube and he bases his figures on the point at which static pressure conditions are recovered after the injection effect. I wonder whether we know enough about the mechanics of mixing of air and gas streams under these conditions.

It seems to me to be highly unlikely that a burner operating on the high air pressures now proposed could produce anything like a homogeneous mixture in the stream upon its entering the tunnel. Perhaps if we could sacrifice a little of the pressure available in arranging a more intimate mixing we might achieve a higher rate of combustion per unit volume of tunnel.

As for the future, we must all give serious thought to the implementation of this work, and I hope that the burner manufacturers show a high degree of interest in marketing burners and appliances designed in accordance with the data. There is a great deal of work yet to be done in achieving the practical design of a burner that will stand up to the conditions found in practice and the question of the most suitable type of refractory to be used has, I am sure, not yet been resolved, although the work progressing at Solihull is of great interest.

At Birmingham we have found that there are practical difficulties in maintaining a gas tight joint at the entry end of the combustion tunnel when the tunnel is made in two sections. In order to build a tunnel having a slot type nozzle without joints, we have recently been experimenting with the lost wax process of making up the tunnel core. This technique shows some advantages, but I am sure that there is still a lot of work to be done in determining the best castable refractory to give high refractoriness, freedom from spalling, good insulating properties and freedom from noise.

We have also found that where slot type jet burners are to be built into a setting it is beneficial to have some form of surround for the refractory block in order to provide adequate strength. In this connection we are now investigating the possibility of using a metal grid to form the outside sheath of the casting in place of the conventional sheet metal housing. This grid will be produced from heat resisting steel welded to form a rigid structure. Tests in connection with actual applications for external heating have proved time and again that the efficiency of the application could always be considerably increased if the slot is flanked on either side with refractory or insulating sections.

Critical distance

The increase in efficiency is possible because of the injector effect of the high velocity products leaving the nozzle. Cool air is drawn in and a heavy dilution of the hot gas stream takes place at the point of discharge from the burner. It necessarily follows that the distance between the burner and the work is very critical and should be as short as possible. When the burner is provided with refractory protection against incoming cold air, there is also a gain in efficiency due to radiant effect from the hot side refractories. There are of course some applications, particularly in enclosed furnaces, where the injection effect would be useful in recirculating products of combustion within the heating chamber.

In some applications of external heating, it is convenient to vary the effective width of the burner slot in accordance with a variation in the width of the work being treated. Prototype burners of this type have

been made at Birmingham, and we have found it possible to construct a burner in which the high velocity products can be ejected over several variations in width without either dilution of the stream, due to the unoccupied sections of the nozzle, or any unevenness along the working length. This is done by a system of internal baffles within the burner, so arranged as to eliminate shadow effect.

Comprehensive paper

In his paper Mr. Francis has dealt most comprehensively with the problems involved in the design of burners. He has given us all the necessary information to make up tunnel burners in accordance with the most efficient practice. He has given us practical information as to ignition, flame failure control and for modifications in the burner dimensions when using a range of air pre-heat. What more can we ask?

The work under discussion is one of the most valuable tools in the armoury of the industrial gas engineer, and I have no doubt that it will be universally found on the desks of those responsible for industrial gas plant design.

Mr. R. J. Broomer, F. J. Ballard & Co., Ltd.: My own particular interest in the burners described in the paper lies in the field of their application to air heaters.

As we all know, air blast tunnel burners were originally developed for high temperature furnace work and the heating of metals by direct impingement. However, as development progressed, it was soon made obvious that this type of combustor could be applied as an air heater.

Some 12 months ago, and after considerable experiment with this type of burner as an air heater, my company decided for the first time to apply it to an industrial drying oven application. Four ovens in all were produced, each fitted with burners mounted in pairs. All preliminary test work had been carried out on a single burner installation, and we were a little apprehensive at first as to whether it was possible to control a pair of burners in such a way that balance would be maintained under both high and low firing conditions. There was, however, no need to worry since the burners operated perfectly satisfactorily once preliminary adjustments had been made.

There were several reasons for choosing this type of burner for this particular drying operation, not least of these was the fact that the burner must be capable of firing into a circuit where air was recirculating at up to 25 ft. per second. Then, it was also essential, that the burner should be extremely compact since there was no room for the conventional refractory lined air heater. The burner should also be perfectly stable under both high and low firing conditions. The turn down ratio required would be 4:1, and this came well within the capabilities of the air blast tunnel burner, also even with these exacting requirements it was essential that the price of the combustion arrangement should be kept to a minimum.

On the face of it, with the added cost of the blower and motor together with the rather more complex type of control equipment, the cost would appear to be greater than that of the conventional type suction burner. There are, however, other not so obvious savings, for example, no large air heater was required thus saving an expensive steel casing with its refractory lining, together with the necessary front plate, air slides and burner mounting. Also with the conventional bulky and heavy heaters, it is usually necessary to have supporting steel work or to stiffen the oven casing so that the heater may be fitted to it. With the high intensity combustor, it is, by design, compact and, therefore, requires little in the way of support. This is mainly where the saving lies. When everything is taken into account there is really very little difference in cost between the conventional air heater and the air blast tunnel burner installations. This does not mean to say that one should automatically choose a high intensity combustor for every application. There are very many cases indeed where it is far cheaper to install the conventional type heater and, further, desirable to do so.

Refractory life

Being our first experience with tunnel burning in the drying field, we were naturally very concerned about the life of the refractories. Both porous and non-porous castables were experimented with of a type similar to those described by Mr. Francis in his paper. Unfortunately for us, these very rapidly broke down. Obviously, we had very quickly to look into the possibility of producing a refractory to stand up to this rather arduous duty.

It was originally thought that the temperature involved within the burner tunnel was in the region of 1,300°C. Our readings taken with an optical pyrometer during the development were, unfortunately, not correct and, in fact, later readings of 1,700 to 1,750°C. were observed. It was, with this new temperature in mind, that the later refractories were developed. These ovens have now been in operation for four to five months, and I can now report that the refractories have an average life of 1,500 hours which we consider is perfectly satisfactory for an application of this type.

The refractories themselves are reasonably cheap, easy to produce and can be replaced within a matter of an hour or so. Breakdown is a very slow process and there is adequate warning prior to complete failure, so that any maintenance work can be carried out outside production hours.

Noise level from tunnel burners has always been a very big problem and, admittedly, these burners are noisy particularly when firing in the open. Fortunately, when applied to industrial drying ovens the burner is buried behind the insulated casing of the oven itself, and since the whole of the oven circuit is usually insulated, the noise is kept down to an acceptable level. Our experience with the four oven installations has been that with eight burners, firing at full bore in a building which is only 14 ft. to the eaves, we have not had any complaints from personnel working in the immediate vicinity.

Higher capacity

Experience with this type of burner until recently has been limited to those not exceeding 1,000 cu.ft. per hour of gas capacity. However, at the present moment we are installing a burner capable of 7,000 cu.ft. per hour, and preliminary tests have proved that it seems to work happily under both high and low firing conditions. The control of this high capacity burner is similar to that described in the paper.

Mr. C. J. V. Denning, Incandescent Heat Co., Ltd.: Since last year's meeting, my colleague Mr. Wright and I have made several burners to designs taken from the paper on jet burner design by Messrs. Francis and Jackson, and on the whole they have been very successful.

The difficulties we experienced previously with refractories appear to have been overcome by using secer and fused alumina in all cases, and wherever possible, metal formers as an alternative to greased wooden formers. But we are now trying a lower grade of refractory and seem to be getting away with it.

Most of our burners have been of Type C (parallel injector, tapered tunnel, designed for maximum pressure efficiency) and we have also given some thought to ignition and flame failure problems. We favour high tension spark ignition as being less

likely to have operating failures than the resistance heated plug. In our experience glow plugs can easily fail to work through slightly corroded terminals, as well as any other cause of increased resistance or through any cooling effect.

We have used the conventional 14 mm. motor car sparking plug, placed about eight diameters of the mixing tube away from the air injector. Ignition has invariably been instantaneous, and on switching off the spark, the flame travels forward and stabilises on the end of the tube.

Since the back of the tunnel is usually relatively cool, we have considered the possibility of introducing a flame conduction probe into the tunnel through the mixing duct for flame failure on larger burners. I should like to know whether the author considers this feasible.

The burner on which we have done most testing has been a Type C design for burning 600 cu.ft. per hour town gas in a heat exchanger with recirculated combustion products, and it requires 28 in. w.g. pressure of combustion air at the injector. The burner casing in this case was made of 13% chrome iron because of the need to withstand recirculating combustion products at about 450°C. passing over it. With this burner we obtain a turn down of about 5:1.

The smallest burner we have made is again Type C, and this will burn 15 cu.ft. per hour at 30 in. w.g.; but it is intended to run from a pressure air main and will pass from 85 to 120 cu.ft. per hour of town gas with air pressures of 9 to 12 p.s.i.

The ignition in this case is by Lodge model engine high tension plug placed about six diameters of mixing tube away from the air injector. The problem with this size of burner is one of manufacturing to the fine limits called for in dimensions of injector mixing duct and tunnel. In general we are finding that our burners are running slightly air rich under nearly all conditions.

Chief drawback

We have drawn up designs for several air blast tunnel burners of larger sizes ranging up to 10,000 cu.ft. per hour, but we have not yet succeeded in getting one on a job. One of the reasons for this is the cost of the gas, especially where people already have oil burning equipment installed gas is simply not competitive. But the main drawback has been the cost of the auxiliary appliances which seem to become disproportionately expensive in the larger sizes. Since one of the very attractive features of this type of burner is its ability to handle large flow rates of gas within a single compact block, it is disappointing that in, say, a large direct fired heater which starts off as a simple looking appliance, becomes an extremely expensive one with all the auxiliaries attached.

Mr. G. Robertshaw, North Western Gas Board: I should like to discuss the construction of the burner itself.

The first point concerns the mixture tube and burner nozzle. To refer to [p. 20, Fig. 10], the mixture nozzle is shown to be of apparently thin wall tubing. We are used to seeing quite the opposite in the conventional burner which is either of cast-iron or heat resisting steel. There is a reason for the increased weight of the previous construction in that it reduces the effects of overheating when an appliance is shut down. I should like to know whether the author has had any trouble with overheating of burner nozzles with the new design. If this is part of the experimental work referred to as being necessary to confirm the life of the burner, could I suggest that it might be accelerated by such a simple expedient as embedded thermocouples in the walls of the end of the tube so that the temperature rise can be ascertained in a matter of days instead of months?

Although pressure losses remote from the burner do not come within the scope of the burner, I should like to draw attention to [p. 29] which illustrates a relay valve on an air supply. Although it is a schematic diagram, it does simulate an appliance on 'high-low' control. It may be worth noting that pressure loss was equivalent to 80 ft. of piping, and the size will have to be increased or, alternatively, a valve with lower pressure loss used in its place.

[Section VI] dealing with ignition and flame-failure equipment is a very valuable contribution to the subject. The words in that section which caught my eye were 'This is, in any case, necessary to be competitive with automatic installations using other fuels.' I think that should be in capitals and underlined. Any further work would be appreciated on this, but I would support the speaker who said that high tension sparking ignition was an advantage, as we are already using this in our tunnel burners.

The author mentions in conclusion a list of future work, and one item is the heat transfer of local heating. That happens to be last on the list, and I would suggest that the order should be reversed and that particular item put first. The industrial engineer of the district can more readily appreciate and put over to clients the use of this burner by very simple experimental figures than by any amount of theoretical work.

Mr. R. H. Anderson, Industrial Gas Officer, North Eastern Gas Board: It was pleasing to see that the promise of slot design opposed to round wall burner design has been carried out, and I was interested to see that by means of pressure flow conditions, as shown in [Fig. 16], the burners have slot lengths up to 4 in., and that the discharge velocity only varies some 3% from the ends to the centre. The author has not given us any figures for burners of longer slot length, and he has not said whether under these conditions we could expect similar figures for a 3 in. deviation from the centre to the ends.

Necessary diameter

When considering [Fig. 18] it is noted that air nozzles are formed by drillings within the dividing plate between the gas and the air chamber. What does the author consider the necessary diameter of such holes to be when considering their diameter of channel to length ratio to give similar jet conditions of ordinary nozzles as applied in the previous experimental work. If it is necessary to have a long channel it means that we shall have to have a thick plate, or a portion of the plate built up to give us its necessary channel depth. If, on the other hand, the author is satisfied that the standard hole through $\frac{3}{8}$ in. plate is satisfactory, does it alter the dimension from the tip of the nozzle to the base of the mixer tube, shown as being $1\frac{1}{4}$ times the difference of the nozzle diameter and the tube diameter.

The use of preheat will extend the range of use of the burner.

Mr. H. R. Hems: I am delighted with the progress which Mr. Francis has made following his paper with his co-author last year. I am particularly glad because it offers one of the greatest possibilities of increased gas consumption and increased service to the consumers in the manufacturing industries than any other application which we know of today.

I refer of course to the possibilities of local heating which, in addition to the oil competition which has been mentioned by one speaker, has also been very severely attacked by the electricity industry. To this end I pay tribute to the author and make two suggestions. They are that the research workers in Solihull have a look not only at the tunnel burner but also at the mixing end.

When the CC burner was first brought to my notice by Mr. Palser, I had a very great difficulty to over-

come. It was a practice of the former Birmingham Gas Department that officials who brought out something new should also take part in any patent that was going to be issued in connection with it. I was in the situation of having to tell Mr. Palser that unfortunately it would not be possible to proceed with the patent, and the reason was that if one looked at the work done by Hammond, Krupps of Germany, and that of the American Service Combustion Company, one could not take patents out of a new type of concentrated combustion burner. On looking at the Hammond burner it will be seen that it is a most perfect type of tunnel burner, and has all the ignition that is wanted attached. I think it will be found that a big portion of its success is due to the fine intimate mixing arrangement made behind the tunnel.

Professor M. W. Thring, Sheffield University, in a written contribution, said: This paper seems to me to complete the development experiments necessary to bring the tunnel burner to a stage when it is available for the furnace designer to match into his plant. The design is carried forward a long way by the realisation that a much greater proportion of the overall pressure head can be converted into dynamic head of the gases flowing out of the burner mouth and less of it is necessary to overcome friction and jet losses than was previously considered to be the case.

Empirical rules

This is another example of the way in which a better understanding of the fundamental processes going on enables the earlier empirical rules to be greatly improved, analogous to the 'B.I.S.R.A. Burner' for oil firing, in which it was shown that a considerably greater fraction of the total heat of the steam used for atomisation could be converted into momentum of the emerging oil-steam stream than had previously been considered possible when the processes were not fully understood.

In any high intensity combustion systems there are essentially two problems, (1) to maintain flame stability so that the flame neither blows out, nor, if the system is premixed, blows upstream and (2) to obtain nearly complete combustion with a low excess air in a given volume. The new work in this and previous papers by Mr. Francis on the tunnel burner seems to indicate clearly that combustion is stabilised by the same mechanism as in high intensity oil combustion, namely, by the recirculation of combustion products from a position downstream where the reaction is nearly complete, which are drawn back and mixed in rapidly with the incoming cold fuel/air mixture to bring it to a reacting temperature. In the case of the homogeneous stirred reactor, the so-called Longwell Bomb, which used sonic jets of premixed fuel vapour and air projected into a highly mixed reaction space, it was found that volume reaction rates of the order of 10^8 B.t.u. per cu.ft. per hour could be obtained provided the incoming mixture was stirred up with about four times its weight of reaction products. A smaller degree of recirculation gave a lower reaction rate because the temperature was not sufficiently high, while a higher recirculation ratio gave a lower reaction rate because of the excessive dilution of the fuel and air. It would be extremely interesting to compare the reaction rates and mixing conditions in these tunnels with the conditions in the Longwell Bomb and with other oil firing systems whose combustion intensity is shown as a function of the pressure drop across the inlets divided by the absolute pressure in the combustion chamber in Fig. 1.

In any case, however, the present work seems to indicate clearly that the function of the sudden expansion into the combustion chamber is to give a sharper shoulder so that the incoming cold mixture starts as a reacting jet down the axis while combustion products are recirculated in tight enclosed eddies in the corners as indicated in Fig. 2 of the paper. I believe that in some earlier work it was considered that the noise was an essential accompaniment of this type of high intensity combustion, but the present work indicates that this is not so, as combustion does not require a sonic oscillation of pressure travelling up and down the combustion tubes and the noise is purely the normal consequence of the high velocity jets involved, just like the noise from a jet aircraft where the total sound intensity is proportional to the eighth power of the velocity.

Stable combustion

The author shows that stable combustion without lighting back can be obtained with a premixed burner even when the air is preheated up to the astonishingly high value of 1,000°F., but I should like to know whether it is possible to develop the burner of the type 'E' with nozzle mixing and higher preheated temperature, but with the same pressure efficiency as burner 'C,' as I can visualise a number of uses where one wants in effect to inject high velocity adiabatic combustion products burnt with very little excess air, but with highly preheated air. This was, for example, the kind of flame we wanted in the continuous counterflow steel melting experiments which we have been carrying out in the last four years at this department except that we did not necessarily need the very high gas velocity.

Best purpose

The paper leads one to ask oneself for what type of industrial purpose is this excellent type of burner best suited? In general one wants a very high combustion intensity wherever it is necessary to burn a lot of fuel in a small volume, whereas one wants a low combustion intensity when there is a danger of overheating one end of the furnace or overheating the charge in one part of the furnace compared with another. As far as boilers are concerned, it is in ships' boilers that the high intensity combustion is most desirable because space is at a premium, but even in some cases of land boilers there is a need for very rapid production of steam in a smaller space which might well be met by gas firing with this type of burner. The use of the burner to give rapid heating of metal parts in the open, as was discussed by Henwood in his paper to the A.S.M.E. combustion conference is one possibility, but open air heating is bound to be wasteful of fuel compared with a properly designed furnace, and should therefore only be recommended when it is required to heat a small part of a large structure or to heat pieces of unusual shape very occasionally.

Inside furnaces for low temperature heating the burner is only advantageous if it is combined with strong canalised recirculation to even out the temperatures, but as shown by earlier work, in this case the use of the high velocity gases from the burner to induce the recirculation can be quite an attractive method as it does not require fins. Probably the burner can be run with a slight air deficiency so that an atmosphere of incomplete combustion can be obtained in the low temperature recirculation zone, although for annealing and heat treatment of steel one had to burn the fuel with only about half the theoretical air.

It is probably, however, in small furnaces for high temperature heating that the burner should most come into its own in cases where preheated air can be used from a top quality metallic recuperator and high heat transfer rates can be used as a result of forced convection from the high gas velocity

Continued on p. 47.

WASHING UP IN THE CANTEEN

Gas takes out the drudgery, says Gastronome

THERE are many tasks that combine to run the industrial restaurant and none is more important than that very necessary one of washing up. It is a job which lacks the interest and pleasure of the others and is usually delegated to the lowest paid worker.

This should not be so, but, let's face it, it usually is in spite of the demands of Parliamentary legislation that the standards of washing up and washing up equipment should be high and that the task should be approached with intelligence by those whose duty it is to carry it out.

It has been said that a kitchen can be judged partly by the cleanliness of its appointments, crockery and cutlery, and partly by the standard of hygiene practised in it. If that is so, it is most important that the operation of washing up should be raised to one of dignity and efficiency, so that as a job it is sought after by the catering workers in our industrial restaurants.

Value of load

How does this effect us in the gas industry? The high gas load from the various methods of water heating utilised in the operation is of considerable interest to us. What is the load worth? As a conservative estimate, it amounts to 5 mill. therms per annum in industrial catering alone, a very fine load to have, and an important load to hold and to consolidate. Let us therefore review the position and see what equipment is available for the job.

The requirements of a washing up installation. In most dish washing appliances water is required at two different temperatures, 120°F. for the washing process and 180°F. for rinsing and sterilising—temperatures over 180°F. do assist in specialised and more positive sterilising, but 180°F. is a safe and reliable figure and in hard water areas is desirable. These temperatures do in fact satisfy the requirements of the food and health inspectors. There are three general types of automatic dishwashing machines in use:—

1. Spray jets at precision angles.
2. Brush and immersion.
3. Agitated water and immersion.

Spray jet machines. Carrier hoppers conveying the crockery into a closed compartment and jets of cleansing water are sprayed from every angle all over the surfaces. Water at a higher temperature is then sprayed to rinse, sterilise and dry the crockery. In the larger models this is sometimes done in a second compartment. It is usual to have two operators working these machines to keep the hoppers stacked and moving and for unstacking.

A detergent is usually mixed with the washing spray and in most models dried egg and mustard are easily removed by the spray of water. Makers of this class of machine are Benham & Sons, Ltd., W. M. Still & Sons, Ltd., Dawson Bros., Ltd., and Hobart Manufacturing Co., Ltd.

It is necessary to install tabling to and from the machines to convey the hoppers into and out of the compartments. This type of washing machine is capable of dealing with upwards of 10,000 pieces of crockery per hour, that is 3,000 meals.

Brush and immersion dish washers are very popular and have come into prominence in recent years. They consist of three sinks or compartments. One is filled with water at 120°F. and has revolving brushes immersed in the water. The plates are fed into the brushes by hand until clean and are then placed vertically in a hopper which holds 10 to 12 plates; they are then immersed in the second sink containing water at 180°F. for rinsing, sterilisation and drying. A second hopper is then filled with cleaned plates ready to replace the hopper in the rinser and so the operation goes on. In the hands of a competent person this type of machine can handle upwards of 3,000 pieces of crockery per hour. The third sink, which is smaller than the others, has a different shape brush for cleaning cups and mugs. These are rinsed and sterilised in the second sink containing water at 180°F.

Dishwasher merits

Agitated water dishwashers are built as two or three compartments machines, in which one or two sinks may have electric-operated paddles to agitate the water against the dishes. The three tank models have two such sinks, the two tank model one only, the other sink being for rinsing, sterilising and drying in each case.

All three types of washer have their respective merits; the 'brush' and 'agitated' machines have a special advantage in that should the power fail for any reason, washing can continue by hand as in ordinary washing up sinks. It must be realised, however, that automatic though these machines are, they depend entirely upon manual operation to create the speed and efficiency of throughput. It is important then to have a skilled operator to handle this task of dishwashing.

A word on 'sterilising' as it refers to these machines. The action is to rinse the detergent and grease film away from the surface of the plate, and by leaving it in water at 180°F. for a period of 15 seconds or longer all harmful bacteria are destroyed and, since the temperature of water heats the plate, it assists in drying it. These plates are hot enough to be used for immediate service after going through the hot cupboard or direct to the counter.

Two sinks

In catering establishments where there are no dishwashing machines, legislation demands the use of two sinks for washing up, the one to contain water at 120°F. for the washing and the other, water at 180°F. for the rinse. The second sink will need a source of heat to maintain the water temperature. This is effectively provided by gas burner equipment such as supplied with the standard 'sterilising' sink made by Adams & Son (Engineers) Ltd., Benham & Sons Ltd., James Stott & Co. Ltd., Black & White (Accrington) Ltd. James Stott & Co. Ltd. and Benham & Sons Ltd. make a special two sink suite admirably suited for the small job of specialised washing up.

The gas industry is clearly well served by the appliance makers with the right equipment for any problem that confronts it in the sphere of industrial catering and it is incumbent upon us to promote the right appliance for the job. It is necessary to know a little more of the means of heating water when this is independent of the equipment itself. We are fully conversant, it can be assumed, with the conventional hot water boiler, but it is often convenient to use an instantaneous water heater capable of producing water up to 180°F. Two such water heaters are in production, made in about four different sizes and maximum outputs. They are the instantaneous water heater made by Jackson Boilers Ltd. and the series of 'Autoheaters' by James Stott & Co. Ltd. They are used extensively in dishwashing installations either as single

or multiple units. Both models are self-contained in that they have their own cold water feed tanks. They are thermostatically controlled at the heater itself, but the temperature of the draw off is determined by the rate of flow through the heater itself. This of course can be regulated by manual adjustment.

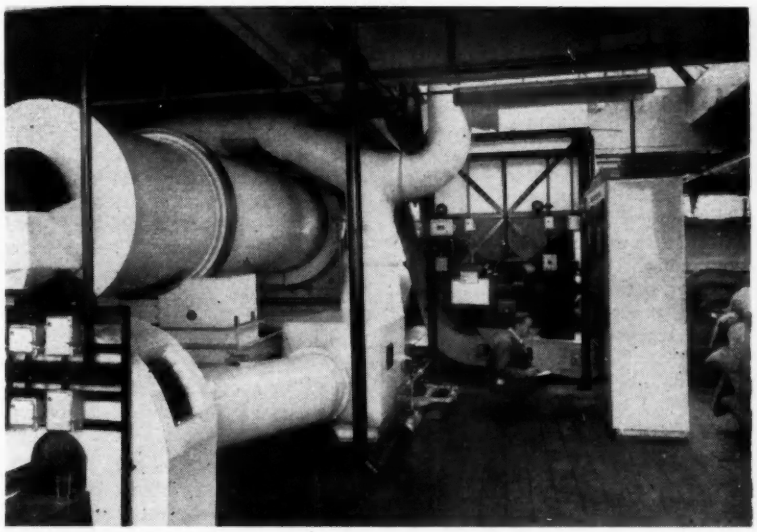
We require to know as much about dishwashing as we can and a knowledge of detergents is recommended. Such information is readily available from I.C.I. Ltd., Domestos Ltd. and the other leading manufacturers of detergents. This is a specialist subject in itself, and needs to be considered in conjunction with the particular installation and the locality of the water supply.

It is important to remember that the cost of an efficient dishwashing installation is related to the importance of the task itself. The cost, therefore, cannot be too high; even so, with a gas installation the estimated capital cost need only be 5s. per meal per five years life, and the fuel running cost one therm of gas per meal per year—small costs you will agree which leave a wide margin for employing efficient labour to operate the installation.

Roasting cocoa nibs by gas

WITH the taste for chocolate-coated confectionery of all kinds growing yearly, the production of the basic raw material, cocoa, has had to be increased to meet the new requirements. To this end new gas-fired plant to roast an estimated 1,000-1,500 lb. of cocoa nibs an hour has recently been installed in the premises of a firm in the South of England.

The direct air heater is fired by three Hypact burners having a combined maximum gas rate of about 2,500 cu.ft. per hour at normal mains pressure with the combustion chamber maintained under a slight vacuum of approximately ½ in. w.g. by a fan capable of handling 3,500 cu.ft. per minute of air at 225°C.



A view of the cocoa nib roasting plant showing the control panel.

Automatic control

The temperature of the air entering the roaster is 225°C. nominal, but the control system enables this to be varied between 150°C. and 300°C. if necessary, although this normally only applies during starting up and shutting down. The ultimate temperature of the roasted nibs is 140°C. An automatic controller measures the exhaust temperature and modulates the inlet temperature to the roaster through a spring-loaded air pressure operated valve working in conjunction with an independent manually operated by-pass.

Initial lighting is provided by a spark ignition system and the plant is safeguarded against flame failure by a photoelectric cell linked through the control panel on to solenoid operated valves on the main and pilot gas lines.

All the many electric motors driving various pieces of equipment are interconnected for sequence, starting from the control panel in such a way that the installation is foolproof and safe.

The ancillary automatic weighing equipment and control panel, together with an impregnator of their own design was supplied by Dunford & Elliott Process Engineering of Victoria Street, London, S.W.1.

The installation of the gas supplies was carried out in conjunction with the North Thames Gas Board.

DESIGN OF AIR BLAST TUNNEL BURNERS

(Continued from p. 45)

and from the fact that the fuel is clean. Tunnel kilns for ceramic firing would provide one example if a number of burners were used, so as to distribute the region of first impact of the high velocity gases over a fairly large area of each car. Steel and non-ferrous melting, at any rate on the small scale, also provide interesting possibilities, especially for the new methods of higher thermal efficiency which are now being developed and which would not be so dependent on luminous radiation as the main mechanism of heat transfer as is the open hearth furnace. In any case, the high velocity of sulphur free gases could give a very high convection heat transfer rate. This would be especially useful for melting the piled up scrap.

In these applications the high intensity combustion is desirable because it gives almost an adiabatic gas temperature with thus the highest possible temperature difference between the combustion gases and the charge, and if the charge leaves the furnace at a temperature of the order of 1,600°C., this is clearly very important.

Mr. W. E. Francis said he would reply in writing.

'INDUSTRIAL GAS ENGINEERING'

Walter King Ltd., publishers of the 'GAS JOURNAL' and 'GAS SERVICE,' are pleased to announce that the North Western Gas Board have entrusted to them the production of Mr. H. P. Lupton's textbook on 'Industrial Gas Engineering.'

The work extends to three volumes, respectively the general commercial and industrial aspects of the subject. All are profusely illustrated.

Autumn publication is anticipated and prospectuses will be available within a few months.

IMMERSION TUBE HEATING OF AQUEOUS LIQUIDS

By

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A SURVEY has been conducted of 63 immersion tube heated systems operating under factory conditions, and the results subjected to mathematical analysis and compared with those of previous workers.

Although the results are not sufficiently precise to give more than a broad picture, this is a consistent one, and is felt to be an improvement over that previously available.

It is particularly pleasing to find that a theoretical analysis of the problem has led to an equation giving closer agreement with the experimental values than more empirical expressions, and this equation is put forward for interim use as a design formula, pending the results of further work that is suggested.

Thermal efficiency of tubes working under natural-draught conditions has been found to be substantially independent of heat input rate, so that, in designing an installation, it is first necessary to select a tube diameter, based on combustion considerations, and then decide its length by use of the equation referred to above.

Wide field

There are many applications of town gas to industrial heating in which the gas is burned in a tube, the useful heat passing through the tube walls, and detailed information on the fundamentals of combustion and heat transfer in tubes has long been desirable. The field is wide, since it includes radiant tube heating, indirect-fired air heaters, steam raising, and a whole host of liquid heating applications, these including frying, oil boiling and soft metal melting. This paper confines itself to one important section of this field, namely, the heating of water and aqueous solutions.

Until relatively recently, published information on this subject was almost entirely derived from a research project carried out by the American Gas Association and published in 1944. This work was based on the use of natural gas, and employed a fixed flue-gas analysis, but the equation based on its results has been widely used for design purposes in this country; indeed, there was virtually none other available.

In order to amplify the available information, some experimental work was commenced at Watson House about 12 years ago, but was stopped when it proved possible to institute a series of researches in the Chemical Engineering Department of the Battersea Polytechnic Institute (now Battersea College of Technology). Results of a number of these have been published; further projects in the same field are in hand.

Performance survey

In January, 1956, a survey was commenced of a number of immersion tube heating installations situated in the area of supply of the North Thames Gas Board. The object of the survey was to discover what performance, as measured by thermal efficiency, is in fact obtained under district conditions, and to endeavour to reconcile these values with those predicted by the use of the formulæ arising from the various laboratory researches.

A large number of tests had to be carried out, nearly all on consumers' premises. Unlike most work done on such premises, it was not obviously connected with helping the consumer; this made it more than ever necessary to minimise disturbance of production. Fortunately, with an immersion tube, all the heat liberated by combustion is dissipated either by passage through the tube wall, or as heat in the flue gases, which means that it is necessary to measure two only of these quantities.

At each installation, in turn, a check meter was fitted before arrival of the laboratory staff. The test procedure then consisted of determining the gas rate and the flue gas composition and temperature. An Orsat apparatus and a suction pyrometer developed by Atkinson at the Midlands Research Station, of the Gas Council, were used. From these results, the percentage flue loss was calculated, and this, when subtracted from 100%, gave the thermal efficiency. In addition, the physical dimensions of the installation were noted, in particular the lengths, diameters and configurations of the immersion tubes, and the heights of the primary flues.

By adopting this simple test procedure, it was possible to complete the work on a single installation in the course of a one-hour visit to a consumer's premises.

Abstract and discussion of a paper to the Autumn Research Meeting of the I.G.E.

Ideal equation

It was hoped that it would prove possible to obtain from the survey results an equation that would apply to the majority of well adjusted immersion-tube installations, and, as such, would be suitable for design purposes.

Ideally, there would be one design equation expressing one dependent variable as a function of a number of independent variable. To obtain this equation in its simplest form, it would be necessary to employ variables that are strictly independent, and this would require a fairly complete understanding of the physical processes involved.

Two-part analysis

Since it was necessary to commence the analysis without such an understanding, it seemed appropriate to adopt an approach similar to those of previous workers, and to attempt to obtain an equation expressing the thermal efficiency as a function of the variables used by other workers, namely, heat input, length, and excess air, and any other variables that might appear necessary or desirable during the development of a fundamental analysis. Following this, it was intended to develop an equation for the flue height necessary to give the required conditions of flow in the tube.

Hence, the analysis of the results was made in two sections, the first dealing with thermal efficiency and the second with flue height.

It is felt that the results warrant the drawing of conclusions as follows:—

1. Analysis of the results of a district survey of 63 immersion tubes has yielded a consistent picture of the behaviour of such installations. The relationship deduced can be explained in terms of the basic physical principles involved, although the precision with which they can be applied is limited by the inevitable lack of certainty in measurements taken under factory conditions. The results, when analysed in different ways, indicate that thermal efficiency increases with tube length, and decreases with increase in tube diameter, excess air and heat input, although in some cases the last two have a statistically insignificant effect.

2. It is not readily possible to select one of the three equations arising from regression analysis of the survey results as being obviously the best to use for predicting thermal efficiencies. The application of results obtained by another worker under laboratory conditions does, however, indicate that the exponential form is likely to be the most precise. This leads to the suggestion that the equation.

$\eta = 80{\cdot}9 - 28{\cdot}3 \exp(-0{\cdot}24\ L/D)$

(Residual standard deviation of $\eta_m = 7{\cdot}5$), where $-$ calculated ther- $_m - 7{\cdot}5$), where η = calculated thermal efficiency (%), L = immersed length of tube (ft.), D = diameter of tube (in.), η_m = measured total thermal efficiency (%), represents the best fit of all the available results, and this is put forward for interim use for design purposes.

Combustion criteria

The absence of a significant term in heat input from this equation may be taken to indicate that there is no optimum value for tubes operating under natural-draught conditions, the maximum heat input being determined by combustion criteria, and is unrelated to thermal efficiency.

Thus, the appropriate design procedure falls into two stages:—

a. Assume a thermal efficiency and hence decide on the heat input required. This permits an appropriate tube diameter to be selected, although no help in this is given by the present work.

b. Once the tube diameter has been decided upon, various values of tube length can be tried in the equation recommended above, until the required value of thermal efficiency is obtained.

3. The use of conventional heat transfer equations of the empirical type normally used for plant design has not given results useful for designing immersion tubes. This is attributed to their inability to take account of the additional turbulence at entry and at bends, etc.

4. A theoretical approach to the problem has shown signs of leading to a more satisfactory form of equation than those obtained from empirical approaches; this is particularly gratifying, since it is clearly the correct method and the only one capable of ultimately leading, by the use of fundamental work in other related fields, to a complete understanding of the system.

5. Three lines of future action appear to offer themselves. They are given here in what is felt to be their optimum order of execution:

i. A study of the best means of applying corrections to the length of the tube in order to allow for extra turbulence caused by entry effects (with which is included the flame) and by changes of direction of the tube.

ii. A refinement of the theoretical analysis of the problem, probably leading to the appearance of flue height, rather than excess air, as an independent variable. This new form of equation could then be used for further regression analysis.

iii. A full analysis of laboratory results obtained from varying diameters of tube. This must await the availability of results from work now in hand at Battersea College of Technology.

The final conclusion is, therefore, that the survey has given a broad picture, which, although lacking in precise detail, has been of considerable help toward understanding the problem, and pointed the way to future work that, it is hoped, will yield more satisfactory design equations.

DISCUSSION

Mr. D. C. Gunn, Deputy Director, Domestic Laboratories, B.C.U.R.A., said: The authors have presented design data which would appear to be greatly superior to those available previously. As they were careful to point out, however, the data provided are not yet complete, information being required, among other things, on the selection of optimum tube diameter to accommodate the combustion of the gases. Their approach, partly statistical and partly theoretical, appears to be extremely satisfactory, although the calculation of coefficients of multiple correlation between the different variables might have provided additional information concerning their inter-relationship.

Some years ago the B.C.U.R.A. adopted similar means for investigating the performance of shell type boilers in industry, and the statistical analyses of the results achieved have been referred to by the authors. This has since proved a most useful yardstick against which the performance of various types of boilers, operating under different conditions, can be judged. The standard deviation of these tests, which covered both Lancashire and medium velocity economic boilers, was 1.7.

The authors from their work have selected an exponential equation in which the only variable is the length to diameter ratio of the tube. Contrary to expectation, and indeed to theory, neither excess air nor area of heating surface appears to be significant. With regard to the former, this may have proved significant had it been possible to choose extreme levels of air: fuel ratio. Under present conditions this may well have been concealed in the residuals. This is a surprising result and, even bearing in mind that the interpretation of the finding should not be extrapolated beyond the data covered by the investigations, some rather interesting conclusions may be drawn which affect the design of immersion heaters.

First, the designer, provided he can burn the gas, need not worry about how much heating surface he must incorporate to achieve a given result. Secondly, he can advantageously make use of tubes of small diameter, which are easily formed to any desired shape. Thirdly, these small tubes take up very little volume in the tank to be heated. Fourthly, he need not worry about excess air.

Interconnected

Having drawn attention to the dangers of extrapolating beyond the experimental data, I am now going to fall into this temptation and do a bit of extrapolating myself! (Mr. Gunn illustrated diagrammatically.) A study of the formula makes one's imagination run riot and, after a little thought, the design shown in [Fig. 1] suggests itself. This shows an immersion heater consisting of a cylindrical combustion chamber which ensures the complete combustion of the gas. This chamber could, if desired, be lined with refractory. The gases then pass along a double pass of small diameter tube at high velocity and exit to atmosphere. The two passes are interconnected by cross pieces through which cleaning brushes can be inserted easily. Owing to the high velocity of the gases, power

beyond that obtained by natural draught must be provided either by means of induced draught or by pressurised combustion. The figure indicates a pressurised combustion system. Assuming a tank 4 ft. 6 in. long by 3 ft. high by 3 ft. wide, containing up to a convenient level 200 gal. of water and requiring that this water be raised through 100°F. in temperature in one hour, it would seem that the following dimensions might apply: Internal diameter of combustion chamber, 6 in.; length of combustion chamber, 1 ft. 4 in.; diameter of exhaust tube, 1 in.; length of exhaust tube, 9 ft. The thermal requirement is 200,000 B.t.u. per hour, and at 75% efficiency this requires a thermal input of 267,000 B.t.u. per hour, a combustion intensity of 1.10^6 B.t.u. per cu.ft. hour. [Fig. 2] shows the equation by Patrick and Thornton and it would seem that optimum working conditions are likely to occur in the range of length to diameter ratio between six and ten. The dimensions of the tube described above came within this range.

High figure

The volume of products of combustion for this data will be about 3,750 cu.ft. per hour at N.T.P., which is equivalent to 310 lb. per hour. This gives a mass flow through the tube of 16 lb. of cross-sectional area per second, a very high figure for any combustion system. The Velox boiler is 14, and it is interesting to note that Brown Boveri used a tube of 20 mm. diameter and a mass flow of 36.9 lb. per sq. ft. second and a pressure loss of 8 lb. per sq. in. Calculations derived from Information Circular 66 of the B.C.U.R.A. suggest that pressure loss for this tube will be 6 lb. per sq. in., a figure which could be easily achieved by using a gas and air premixer. The exit gas temperature would be about 900° F.

A rough check, using the McAdams formula for heat transfer, suggests that under these conditions a tube could, in fact, transfer 295,000 B.t.u. per hour, a figure higher than that assumed to be required. It would, therefore, seem that this extrapolation may not be entirely wild. The heat transfer rate in this immersion heater would be 125,000 B.t.u. per sq. ft. per hour, which is of the same order as that in the evaporator of the Velox boiler.

The trends of modern boiler design are towards the use of high gas velocities in the convection passes of boilers, but in most cases of shell boilers, mass flows in excess of 3 lb. per sq. ft. per second are unusual. The pressure loss over the heating passes of a Velox boiler may be about 8 lb. per sq. in., a figure very comparable with that in the suggested immersion heater design. The mass flows involved in a Velox boiler were up to 14 lb. per sq. ft. per second. Again this is of a very similar order to that in the suggested immersion heater. I would therefore like to suggest that Patrick and Thornton have, as a result of their investigations, given food for thought and imagination in making new approaches to immersion heating techniques. In this connection it should be borne in mind that gas is an ideal fuel for these applications, and for obvious reasons solid fuels and certain oils might give rise to severe difficulties.

Mr. W. A. Lloyd-Dodd, Industrial Gas Officer, Southern Gas Board: The authors' work has provided us with one piece of vital information which makes further work imperative. This is that the existing empirical formulæ of the American Gas Association and Ashton are even less satisfactory than the derived equations already mentioned.

I have called this information *vital*, because of the rapidly increasing and expanding use of immersion tube heating in industry. The heating of liquids represents a major load to the gas industry. Tyrrell has estimated it at 20% of the total industrial load, and the increased use of immersion tubes seems the surest way for us to consolidate and expand this load. While, therefore, it is a bit of a shock to learn of the severe limitations of the design equations we have been using, it is undoubtedly better to know.

Better result

Satisfactory designs of immersion tube installations will mean progress in the field of light metal melting as well as in the heating of aqueous solutions, and it is a pity, therefore, that none of the three regression equations has turned out to be satisfactory as a solution. It is interesting to note, however, that the form of equation derived theoretically gives a much better result than the other two when applied to some of Ashton's laboratory results, even though it was no better when applied to the district results. Whether this is due to Ashton's results being more accurate than district testing or unrepresentative of district practice remains to be seen.

Mr. W. E. Francis, Midlands Research Station: The authors have largely analysed the results of the survey by statistical methods involving the use of semi-empirical regression equations. It is arguable that the use of the resulting equations for design purposes tends to perpetuate the existing designs whether good or bad, since they must represent not the best design but the mean of existing installations.

Rewarding

The authors have rightly tried to obtain guidance on the form of regression equations to use by recourse to a theoretical analysis of the physical processes taking place. We have found that it is very rewarding to pursue this theoretical analysis further and that it can predict the results of the surveys more closely than the paper would suggest. Considering the analysis on [p. 25] of the paper, the three equations 29, 30 and 31 represent the force-momentum equations, the total energy balance and the heat transfer equation respectively. By making simplifying assumptions in the momentum equation, the authors derive equation 32, which represents an exponential decay of temperature in the tube. However, this equation does not behave itself when the tube length is very large, and the authors have to alter it to conform with practice into equation 33. We were somewhat puzzled by the fact that this equation did not behave itself and also was derived from the momentum equation and not, as we would have expected, from the heat transfer equation. In trying to explain this we found that the equation can be derived quite rigorously from the heat transfer equation, 31, and the more usual form of heat balance in which the mechanical energy terms of equations 30 are neglected in comparison with the very much larger thermal quantities.

The momentum equation 29 leads to the pressure change in the heat transfer section of the tube. By combining this with the pressure change at the entrance of the tube due to air entrainment and combustion, and equating to the buoyancy pressure available, due to the vertical flue height, an equation is obtained from which the excess air quantity may be calculated in terms of the physical dimensions of the tube and the thermal input.

The calculation was somewhat lengthy but quite straightforward. We have applied the resulting equation to a calculation of the excess air quantities and hence by means of equations 34 and 35 to obtain a calculated thermal efficiency. Only the gas input rate and the physical dimensions of the system are required to be known if reasonable assumptions can be made about the burner system in use. We have applied these equations to the calculation of the overall air:

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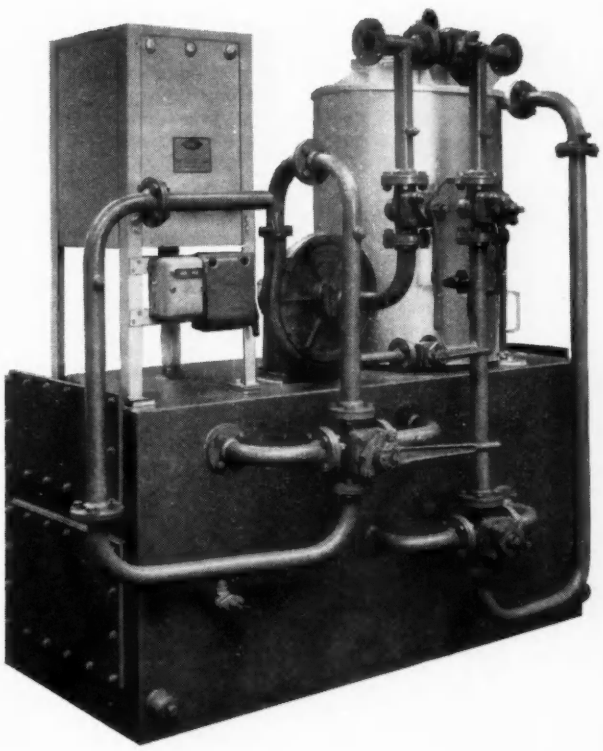

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gas ratios and thermal efficiencies for each separate set of results reported in the survey. For the great majority of the survey results the calculated and observed overall air:gas ratios were quite reasonably close. Only in the case of tubes with no bends were the errors very large, and apart from these cases, the efficiency equation showed a standard deviation of 11.5%. In view of the difficulties under which the survey measurements were necessarily taken, and having regard to the fact that some of the data required for calculations was imprecise, the agreement is remarkable. A series of laboratory experiments, with closer control of variables than is possible in a survey of the kind which the authors have described, would serve to check and if necessary modify the theory to give more accurate predictions. We feel that any future work on immersion tube design could well take this theory as its starting point and that in its final form, the theory should provide a logical basis for design.

Complete calculation

It is an interesting point to realise that as a result of an extension to the authors' theoretical analysis, we are in a position to calculate completely, from fundamental physical principles, the design of this particular type of natural draught appliance from gas nipple to flue terminal.

Mr. J. G. de Voogd, Director, Gas Instituut, Netherlands: The Gas Instituut of the Netherlands has done some work on immersion tube heating and we have published it; but as this was published in Dutch I understand that you have not included it in your literature references.

I can perhaps give you a very short summary We also found that it is very difficult to calculate the mean heat transmission in a theoretical manner. Therefore, we carried out some experiments. We first made tests with an open 2 in. gas tube with wall temperature of about 100°C. The other conditions we chose were an excess of air of 50% thermal efficiency of 80% and a pressure drop of .6 mm. w.g. Then there generally remained enough pressure available for the draught. The results of these tests make it possible for us to calculate the right gas consumption and dimensions of the tube. However, in many cases the tubes were too long for practical use. For this reason we have also made tests with welded strips in the tubes. The same requirements so far as excess of air, efficiency and pressure drop, were concerned were the same as those for unfilled tubes. We found that heat transmission is nearly 70% higher. As a result of our experiments it is possible to calculate the number and dimension of the tubes and to decide whether a strip is necessary or not, and to reach a combustion efficiency of at least 75%.

Dr. S. R. Tailby, Head of Chemical Engineering Department, Battersea College of Technology: In 1949 the only knowledge on the design of immersion heaters was the A.G.A. formula which is seen here. We carried out research in 1949 on this subject, because we felt that it was something which needed to be done. We worked first of all on vertical tubes and then we extended that by the use of turbulence promoters, notably sound, to try and influence the gas film on the walls, and then we went on to horizontal tubes. We are still working on horizontal tubes at the moment.

I do not think that the discrepancy that has been pointed out between the work here and the work that we have done at Battersea is as bad as it looks. For one thing, the great gap in our knowledge is that we really do not know the effect of the diameter. You will see that in the [graph on p. 16] of Ashton's work the points are plotted for the 3 in., 4 in. and 6 in. tubes. In fact, of course, Ashton only worked on 3 in. tube, and I am not at all sure that it is fair to strain these results obtained on a 3 in. tube to cover the case of the 4 in. and 6 in. tube. The results of the 3 in. tubes appear to fit the equations on the other side not too badly. We are working on this at the College of Technology.

There are two other points which I should like to mention. First of all if you look at [Table I] you will see that the Reynolds numbers vary a good deal. They vary from low figures in the region of 1,500 to 1,700 up in some cases to 12,000, 13,000, and so on. I feel that we have not taken this factor sufficiently into account in quite a number of calculations, especially the effect of bends and so on in the pipe. This again is something we are looking into at Battersea.

Simplification

On [p. 20] it is stated that if the flow exceeds 2,300 then it is assumed to be turbulent. If it is less than 2,300 then the streamline form of equation is used. It is rather a simplification because usually what happens is that if you plot h with the Reynolds number, you obtain a series of lines for various h.o.d. ratios and the turbulent region is here. (Dr. Tailby illustrated diagrammatically.) Therefore the figure 2,300 is not as sharp as is suggested. I am aware of the fact that the authors know this as well as I do. However, I think it is a simplification. One of the difficulties with this gas work that I did not know of when I started it, is that one is always working in this transition region, and the transition state does persist over a whole range or region up to 7,000 or 8,000 Reynolds numbers.

On [p. 35] the authors say that in (a) the appropriate procedure falls into two stages. It is necessary to assume a thermal efficiency and hence decide on the heat input required. This allows one to pick the tube diameter. The question is flue height. If you choose the diameter obviously the flue height must come into it to influence the excess air.

Mr. F. J. Johnson, East Midlands Gas Board: I think that from the information given by the authors we have to dismiss equation 1, the expression formulated by the American Gas Association. Therefore, our choice is between Ashton's and the authors' equations.

Referring to the diagram, we find that in the majority of cases examined the equations offered by Ashton give actual efficiencies higher than the calculated figures. The expression given by the authors, while admittedly offering the possibility of a narrower margin of error, presents a 50-50 chance of the actual efficiency being lower than the calculated amount. From the designers' point of view, therefore, there is something to be said for choosing Ashton's equations in preference to the authors'.

Less reliable

On [p. 29] the authors state that equations 45 to 55 are not necessarily suitable for predicting the values of the other variables, apart from the efficiency. That is, starting with a design efficiency, the equations are less reliable in determining, say, the length of the tube required to give this efficiency. Could the authors offer us a guide as to what sort of accuracy we would obtain? Also what they would recommend as the actual tube length, that is, the immersed centre line length, assuming the tube to be 'L' shaped, against the theoretical length.

On [p. 21, Fig. 5] shows that the majority of 3 in. tubes give streamlined flow while the majority of 4 in. and 6 in. tubes give turbulent flow, that is, that the Reynolds number increases with pipe diameter. In the cases under review there is a tendency for flue heights and temperatures to increase with the size of pipe used. Is this the reason for the statement that the Reynolds number is expected to increase with pipe size?

Finally, what in the opinion of the authors, is the optimum heat input

for, say 3 in., 4 in. and 6 in. diameter pipes and has the position of the tubes in the bank any significant effect on efficiency?

Mr. E. A. K. Patrick (in reply): I always find discussion with Mr. Gunn stimulating. It always results in a contact between two different fields of work which seem to overlap in part. It is true that once you go to forced systems you can do a great deal more. We have restricted our work to the natural draught system which will have attractions for many years to come for simple installations.

Mr. Lloyd-Dodd said that his reaction was one of initial disappointment. It was mine as well.

One diameter

So far as Ashton's results are concerned, Ashton worked with one diameter only. That is known and with his figures the correlation which was carried out gave quite reasonable results with reasonably low standard deviations. Our work has been carried out with a mixture of diameters and if you use Ashton's results which were obtained with precision (our district figures were not) it helps to give a lead to our own picture to show what finally might be done. Since we sent in the text of the paper we have done more work and we find that Ashton's own equation, when used with the particular selection of his data which we used to derive equations 52 and 55, gives a residual standard deviation of 3.3 compared with a value of 1.8 which we achieved. Whatever equation one starts with, an answer is always obtained, and we are only suggesting that we chose something different to start with and have hopes of getting an answer with a lower standard deviation in the end.

It is stated that the standard deviation itself can be misleading. I can only say I feel that the time has come when the engineer has to talk in the jargon of most of the other professions and sciences and has also to learn some of the jargon of the statisticians, and in that connection 'standard deviation' keeps coming up. It is a simple mathematical function which comes directly out of the mathematics involved, and it can be directly related to the accuracy of the work. If you double it ± twice the standard deviation is the figure in which nineteen out of twenty of the results would fall; but two-thirds should lie within ± standard deviation. My own feelings on the subject are that I should like to see as a desirable conclusion 1.5 units per cent.

We are very glad we have stimulated Mr. Francis into scrutinising the derivation of our theoretical equation and improving it. We shall study it when we see it written down and feel sure that it will prove useful for further attempts to apply theory to the system. Again I would make the point that it is a contact between two fields. Mr. Francis has for many years been working in the fields which involve him in equations, and it is his background in that field which led him to spot a number of idiosyncrasies of ours.

Great step

He also made a valid point that for the first time we have been able to design an appliance from the gas outlet to flue. That is a great step. Of course, the immersion tubes system is particularly simple to do it with.

We were interested to hear Dr. de Voogd's work in Holland, and we look forward to having a written contribution from him.

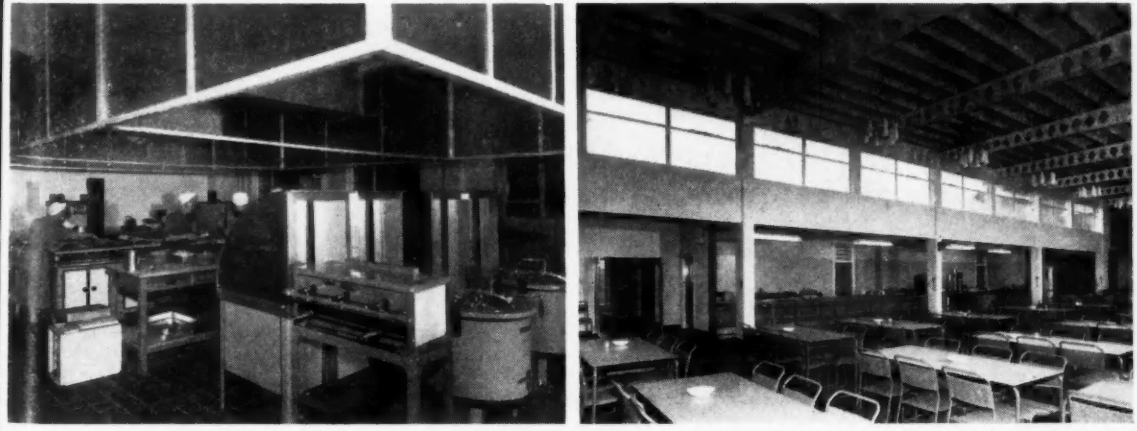
Dr. Tailby told you of his motives for starting this type of work and I might say I was pleased when he took this attitude at the beginning.

Ashton cropped up again, and the suggestion was made that it was not fair to strain Ashton's results. We are not. We are using them as an admittedly limited yardstick. Therefore it would be expected that his 3 in. diameter results would be far better than the results of other diameter tubes.

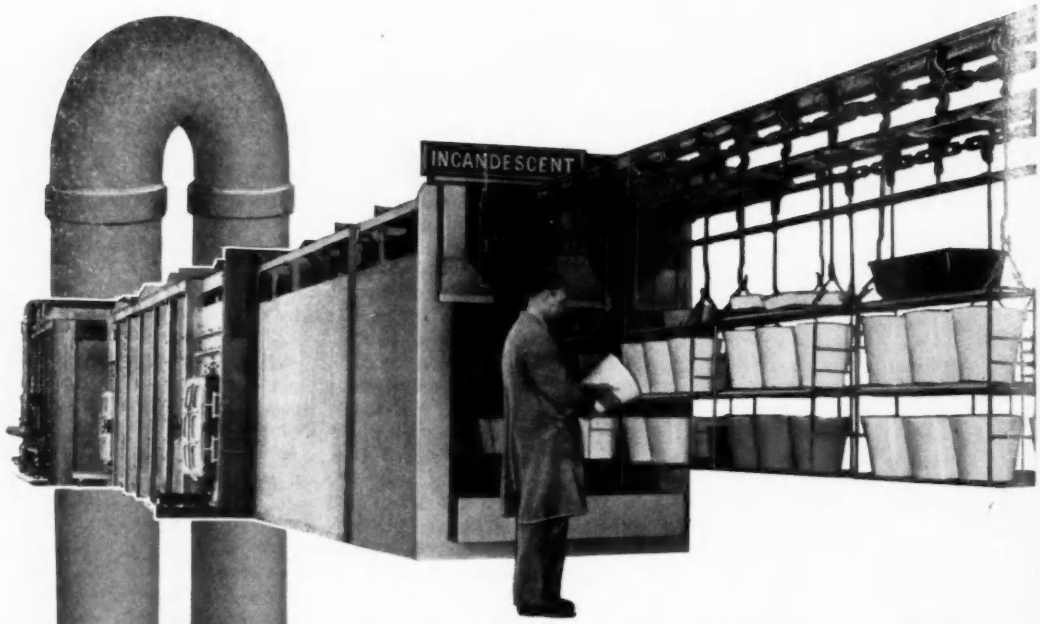
Not easy

As to Reynolds number 2,300, I agree that one should not make a sharp distinction at that value, but he did not tell us what we should have done. That would not of course be very easy.

In reply to Mr. Johnson, our result giving 50-50 high and low figures for design is the direct consequence of the method of their derivation. The statistical method starts at the middle and works outwards, and one always gets this 50-50 effect. We said that the Reynolds number would be expected to go up with diameter because, other things being equal, the Reynolds number is diameter on top of the expression, and for a given rate of mass flow through the tube the Reynolds number goes up, optimum heat being conditioned by combustion quality. It is a function of diameter of the tube and height of the flue. The present paper tells us nothing new about that aspect.



British Tyre & Rubber Industries, Ltd., Leyland, Nr. Preston, have recently opened their new canteen. The equipment, which is gas heated, will eventually deal with 400 meals, and comprises chiefly: Four-oven central range; 7½ cu.ft. steamer; two 2S autofrys; two 20-gal. boiling pans; 200 cu. ft. cold room; dishwasher ventilation scheme; 52 ft. self-service cafeteria counter with cafe set; together with the usual labour saving machines such as slicers, mixers and peelers. All the preparation tables and sink units, which are constructed in stainless steel, were supplied, along with all the catering equipment, by Stotts of Oldham.



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